PRELIMINARY DESIGN OF SYSTEM PROTEC'SYS

International Master on
Control for Green Mechatronics

UBFC

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1. REQUIREMENTS DEFINITION (LOT P10)

PROTEC'SYS systems requirements are defined and described in the following sections.

1.1. GENERAL DESCRIPTION OF THE SYSTEM (LOT P11)

1.1.1. Purpose, mission and objectives

Table 1: Purpose, mission and objectives of the system.

Purpose	Automate a process dangerous for humans
Mission	Move a nuclear waste container from a transfer area to a landfill within a containment zone without any incident
Objectives	Finish the process without any incident or accident
	Avoid any contact between the waste container and the components of the reprocessing center (path, walls, edges of the airlock)
	Avoid any contact between the robot and the borders of the reprocessing center
	Avoid any overturning of the robot while moving inside the reprocessing center
	Avoid losing the path
	Respect the speed limits
	Accomplish the process without discharging

As a team, we also need a purpose, missions and objectives to compete and perform well. They are shown in the following table.

Table 2: Purpose, mission and objectives of the team.

Purpose	Develop system engineering, technical (mechanical, software, ergonomics) and project planning skills within an interdisciplinary team
Mission	Compete and provide a preliminary and final design. Operate and validate the designed system.
Objectives	Do not have to intervene manually during automatic phases
	Complete the mission in no more than 420 seconds
	Design a robot with the appropriate characteristics to accomplish the task requested and fitting the dimensions of the reprocessing center
	Automate tasks that don't require human intervention
	Earn more than 160 points
	Complete the mission in no more than 420 seconds

1.1.2. Organic context

- **External elements:**

  a. Security officer, judges and referee (Staff)
  b. Attendance
  c. Load
  d. Reprocessing center:
    - Black path
    - Maintenance zone
    - Transfer zone
    - Landfill
    - Obstacle (Wall)
    - Decontamination area 1

  - Decontamination area 2

e. Power supply
f. Tools
g. Environment (temperature, pressure, humidity, lighting, noise, vibration, electro-magnetic waves and wind)

- **Links between system and external elements:**

Consider:

- A = Auditive
- P = Physical
- R = Radiation
- V = Visual

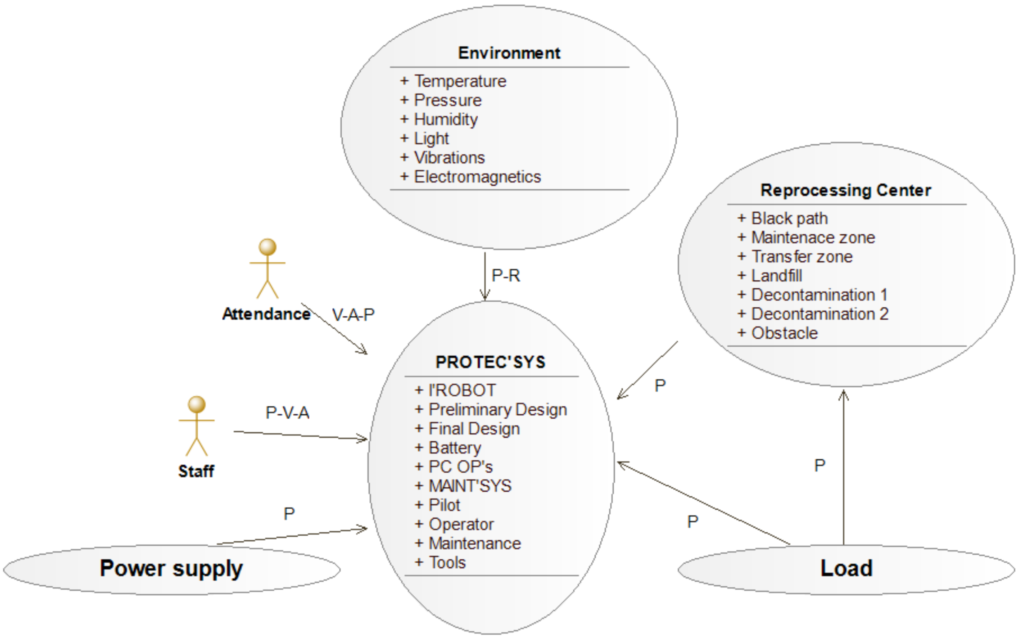

Figure 1: Organic Context

1.1.3. Functional context

The identified functions for the system to interact with its environment are described as follows:

- **Functions:**

  - **Listen:** Receive and process referee instructions, when to start or stop, when to access the track and when to select each one of the modes.
  - **Setup:** Setup and/or do the maintenance of the system before it starts with the process.
  - **Place:** Maintenance should locate the robot inside the maintenance area and load is previously locate inside it by the staff.
  - **Locate:** The pilot and operator should visually localize the robot and the load inside the reprocessing center.
  - **Move:** Send command to the system to execute instructions received and start system movement inside the reference frame.
  - **Carry:** System should move until the load and transport it until the goal area.
  - **Charge:** Recharge the battery when is over.

- **Inputs/Outputs description:** Inputs and outputs of the block diagram are described in Table 3 and shown in Figure 2.

Table 3: Functional context (Inputs and outputs description)

Inputs (Objects)	Description	Outputs	Description
Staff	Instructions and authorizations given by staff.	R_P	Robot position within the reference frame (Track).
Rcenter	Reprocessing center track taken as reference frame.		
Load	Load object placed inside the track.	$Load_P$	Load position within the reference frame (Track).
Tools	Tools needed to setup and maintain the system.		
Power	Electrical power needed for charge		

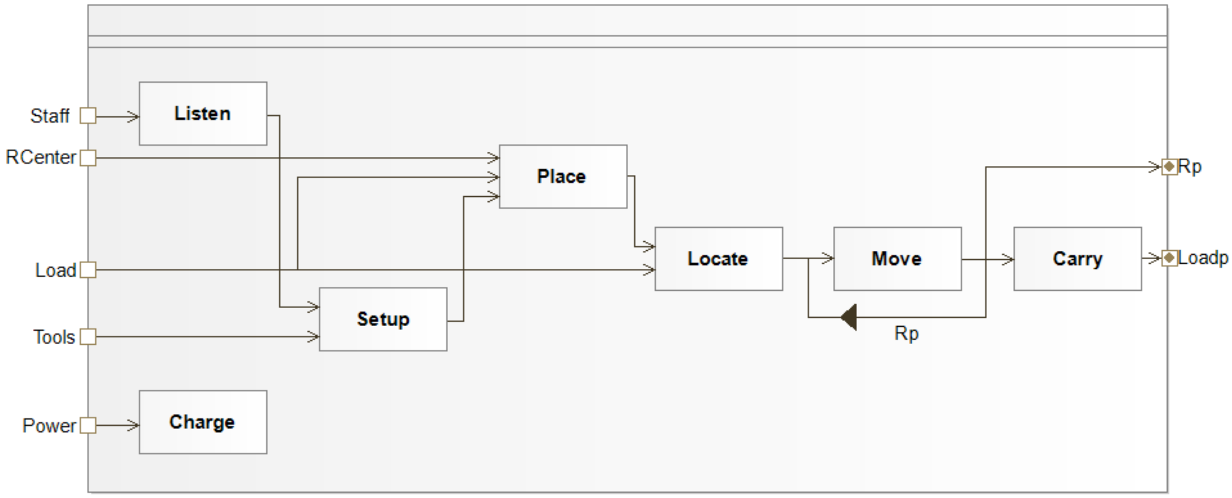

Figure 2: Functional Context

The block diagram above presents the interactions between the system functions and the external elements. Each input is intended to feed a certain function to accomplish the task being performed.

1.2. TECHNICAL REQUIREMENTS OF THE SYSTEM (LOT P12)

1.2.1. Functional requirements

Table 4: Functional requirements.

Function	Requirement	Description
F1: Listen	FR 1.1.	Pilots and maintenance operator follow the instructions of the responsible of security
	FR 1.2.	Each phase of the mission starts when the previous one is accomplished and is validated by the responsible of security
F2: Setup	FR 2.1.	Pilots and maintenance operator calibrate the sensors and check if they give accurate values
	FR 2.2.	Maintenance operator replace a damaged piece if the spare part is available and the battery is drained
	FR 2.3.	Maintenance operator repair a defective component or damaged mechanical part
F3: Place	FR 3.1.	Maintenance operator place the robot inside the maintenance zone to start the task
F4: Locate	FR 4.1.	The robot is located inside the reprocessing center
	FR 4.2.	The robot should detect the black line without losing
	FR 4.3.	The robot must detect each zone
	FR 4.3.	Pilots should have a visual reference of each area

	FR 4.4.	Pilots observe each obstacle to avoid them successfully
	FR 4.5.	Pilots observe the load inside the reprocessing center, specifically at the transfer zone
F5: Move	FR 5.1.	The robot should move forward and backward smoothly as fast as possible.
	FR 5.2.	The robot should rotate right or left when needed as fast as possible
F6: Carry	FR 6.1.	The robot must pick the container when it arrived on the transfer area
	FR 6.2.	The robot must keep the load during the displacement on the track in automatic and manual mode
	FR 6.3.	The robot must carry up the load in the transfer area and drop it in the confinement area
F7: Charge	FR 7.1.	The energy storage provides to the robot the power to accomplish its mission
F8: HMI	FR 8.1	HMI should indicate the state of line detection and color sensor
	FR 8.2	HMI should display the working phase
	FR 8.3	HMI should display the remaining time of the mission
	FR 8.4	HMI can test connection with robot
	FR 8.5	HMI should display the speed of the robot
	FR 8.7	HMI can control robot functions
	FR 8.8	HMI can indicate the working mode
	FR 8.9	HMI can alert the user in case of malfunction

1.2.2. Performance requirements

Table 5: Performance requirements.

Function	Requirement	Description
F1: Listen	PR 1.1	Instructions must be short and comprehensible.
	PR 1.2	The transition between manual mode and automatic mode should be synchronizing by a switching signal to increase reliability
	PR 1.4	Response time of the team must be less than 5s
F2: Setup	PR 2.1	Sensor calibration time must be less than 10 minutes
	PR 2.2	Mechanical systems setup time must be less than 5 minutes
	PR 2.3	The replacing time is less than 20 minutes
F3: Place	PR 3.1	The robot initial position should be optimized to reduce errors when starting the process
F4: Locate	PR 4.1	Detection errors must remain in 0
F5: Move	PR 5.1	Robot can deaccelerate when approaching the curve or path end
	PR 5.2	The mean speed for straight paths is 60 mm/s at 80mm/s zone
	PR 5.3	The mean speed for straight paths is 10 mm/s at 15mm/s zone
	PR 5.4	The maximum rotation radius for curves is 180 mm
	PR 5.5	The robot must be accurate in position when moving
	PR 5.6	The mean rotation speed is 0,033 rad/s at 80mm/s zone
	PR 5.7	The mean rotational acceleration is 1.85x10^{-3} rad/s^{2} at 80mm/s zone
	PR 5.8	The mean rotation speed is 6.67x10^{-2} rad/s at 15mm/s zone
	PR 5.9	The mean rotational acceleration is 4.4x10^{-4} rad/s^{2} at 15mm/s zone
F6: Carry	PR 6.1.	The lifting system must be reliable to avoid losing the load while moving
	PR 6.2.	The carrying system must be able to take the load independently of its position or orientation
F7: Charge	PR 7.1	The energy storage must be integrated in the robot
	PR 7.2	The robot must be autonomous (in energy point of view) during each loop and the robot must save the maximum of energy on the track
	PR 7.3	the robot must save the maximum of energy on the track
	PR 7.4	The storage system used must be changed or recharged as fast as possible to avoid time delays

F8: HMI	PR 8.1	The HMI should be ergonomic and easy to understand layout
	PR 8.2	The HMI should use different and attractive colors to show information to the user to reduce human errors
	PR 8.3	The HMI should provide accurate and understandable information about the system

1.2.3. Interface requirements

Table 6: Interface requirements.

Function	Requirement	Description
F1: Listen	IN 1.1	Auditive: Focused always in staff indications or instructions
	IN 1.2	Assertive communication between team members
F2: Setup	IN 2.1	Physical: Cables, tools, spare parts.
	IN 2.2	Information transfer (physical by USB cable): program uploading to control board
F3: Place	IN 3.1	Physical contact with robot
F4: Locate	IN 4.1	Visual reference: Robot, paths, load, operation areas, obstacles
F5: Move	IN 5.1	Wireless communication: Bluetooth (Emitter – Receiver)
	IN 5.2	Human Machine Interface (HMI): computer software for pilots to control the system
	IN 5.3	Computer (Laptop): holds HMI
	IN 5.4	Microcontroller: communicate with PC'Ops and controls robot
	IN 5.5	HMI – Robot: Simple signal to switch between modes (Auto – Manual)
F6: Carry	IN 6.1	Physical contact between the robot arm and the load
	IN 6.2	Position references to grab and transport the load to its destination
F7: Charge	IN 7.1	Physical: Battery charger and power cords

1.2.4. Operational requirements

Table 7: Operational requirements.

Function	Requirement	Description
F1: Listen	OP 1.1	Communication between team members is accurate and fast
	OP 1.2	Pilots and maintenance operator need to focus all the time and avoid noises or distractions
F2: Setup	OP 2.1	The access to every component of the robot should be fast to optimize repair/setup time
	OP 2.2	Coding is simple, understandable and efficient such that code maintenance and troubleshooting is faster
F3: Place	OP 3.1	The robot is placed in an optimal position for starting, as indicated by the staff
F4: Locate	OP 4.1	Observers (Pilots) should be always at the operation zone avoiding distractions, and focus on the system.
F5: Move	OP 5.1	Automatic Mode: The path following should be smooth
	OP 5.2	Manual mode: The movements such as moving forward and backward, rotating left and right should be smooth
F6: Carry	OP 6.1	The HMI pilot must be sure that the load is stable before moving
	OP 6.2	The handling operator must be well trained
F7: Charge	OP 7.1	The storage system must be easily accessible
	OP 7.2	The voltage usage for each component of the robot must be respected
	OP 7.3	The connection between electrical devices must be efficient to minimize energy loss
	OP 7.4	The battery should provide energy to a device only when it is needed
F8: HMI	OP 8.1	The algorithm should be fast to avoid time and accuracy loss when sending or receiving information

1.2.5. Constraints

Table 8: System constraints.

Function	Requirement	Description
F1: Listen	CT 1.1	Attendance noise
	CT 1.2	Distractions
F2: Setup	CT 2.1	Many elements and connections between them
	CT 2.2	Damage severity
F3: Place	CT 3.1	Maintenance technician cannot go further the white room
F4: Locate	CT 4.1	Sensor precision /calibration
	CT 4.2	Light
	CT 4.3	Controller precision
	CT 4.4	Picking precision
F5: Move	CT 5.1	DC motor power
	CT 5.2	Robot weight
	CT 5.3	Load weight
	CT 5.4	Speed limit 1: 80 mm/s
	CT 5.5	Speed limit 2: 15 mm/s
	CT 5.6	Maximum displacement speed to take curves
F6: Carry	CT 6.1	Maneuverability of the load
	CT 6.2	Carrying and releasing time
	CT 6.3	Position of the load on the transfer zone
	CT 6.4	Weight of the load
	CT 6.5	Ability of the manutention operator situated in command and control center to see the load
F7: Charge	CT 7.1	Time of charging
	CT 7.2	Total energy consumption of the robot
	CT 7.3	Maximum capacity of the energy storage
	CT 7.4	Usage voltage of each electrical component used
F8: General	CT 8.1	Robot architecture is constrained to the provided Make block kit
	CT 8.2	Time is limited to 480s for the whole process
	CT 8.3	Robot measures must not exceed 300 mm long
	CT 8.4	Robot weight must not exceed 1200 g
	CT 8.3	Process must be completed 3 times in less than 4 hours

1.2.6. Validation requirements

Table 9: Validation requirements.

Function	Requirement	Description
F1: Listen	V 1.1	Practice communication between the team members
F2: Setup	V 2.1	Test different calibration and repairing strategies to select the best and fastest one
	V 2.2	Every crucial part of the robot must be mounted and dismounted easily
F3: Place	V 3.1	Test different starting positions of the robot to define the best starting point
F4: Locate	V 4.1	Test sensors several times
	V 4.2	Vary line detection algorithm parameters and search for the ones which provide the smoothest and fastest response
F5: Move	V 5.1	Test each phase change algorithm with different command signals to select the most reliable one
	V 5.2	Go through the whole track several times and measure times with different speeds to select the best set up
	V 5.3	Repeat each manual mode movement (Forward, backward, left, right) to calibrate

		algorithm, speed and acceleration to have better stability and make a good track time
F6: Carry	V 6.1	Carry the load with different grapping systems to select the best one
	V 6.2	Vary speed and acceleration with the load being carried to determine the best strategy
	V 6.3	Perform load drag and drop several times and in different positions to select the best strategy
F7: Charge	V 7.1	Try different batteries and measure their charging times and autonomy to select the most appropriate
F8: HMI	V 8.1	Test HMI functions several times to identify and fix problems with coding and communication
	V 8.2	Test that the designed interface is easy to use by giving brief instructions to a person that doesn't know about the process and allow him/her to control the prototype
F9: General	V 9.1	Robot measures must not exceed 300 mm long
	V 9.2	Robot weight must not exceed 1200 g

2. ARCHITECTURAL DESIGN OF THE SYSTEM (LOT P20)

2.1. GENERAL DESCRIPTION OF THE SYSTEM (LOT P21)

During this section we will consider different possible solutions that might be implemented for the system in order to satisfy the constraints and accomplish the task. To simplify the selection procedure, we will divide the system into sub-systems.

2.2. FUNCTIONAL AND BEHAVIORAL ARCHITECTURE OF THE SYSTEM (LOT P22)

2.2.1. Static functional tree

PROTECT'SYS system functional tree describing the main functionalities and its operating modes is shown as follows.

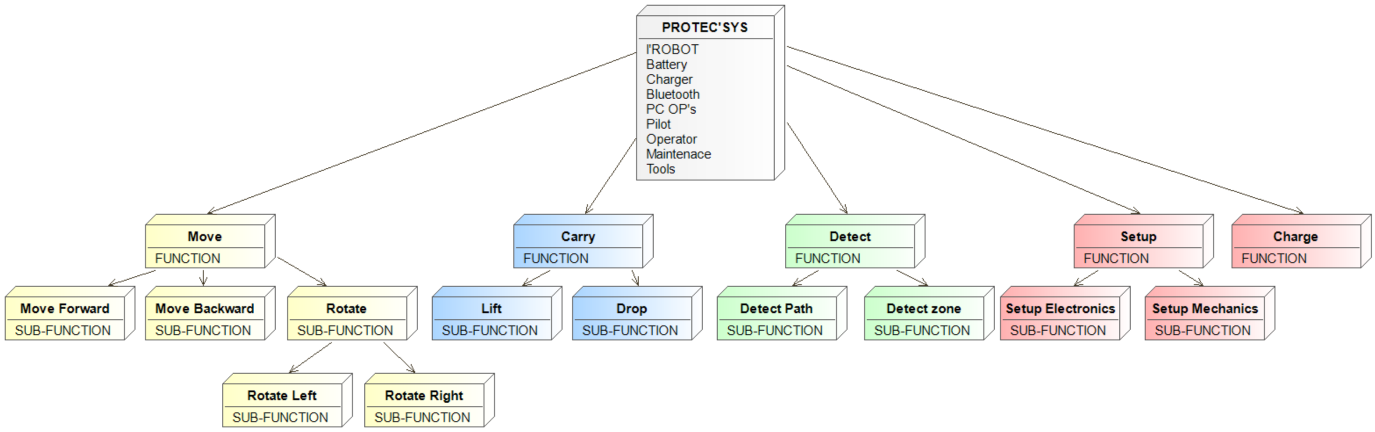

Figure 3. Static functional tree of the system.

Where red colored functions are performed at the stand by operation mode in which the robot is not performing any action; blue colored functions are performed in manual control mode in which the pilot and operator can command the robot. For automatic functions the color selected was green, meanwhile functions which are performed in automatic and manual mode are shown in yellow. Each function with its subfunctions is described as follows:

Table 10: Static functional tree description.

Function	Subfunction	Sub-subfunction	Input	Output	Interfaces
Move	Move Forward		Forward command	Robot moves front with constant speed	Pilot through PC OP's keys, commanding IHM, sends a wireless signal using Bluetooth modules to I'ROBOT control board which activates wheels motors.
	Move Backward		Backward command	Robot moves back with constant speed	
	Rotate	Rotate Left	Left command	Robot rotates left	
		Rotate right	Right command	Robot rotates Right	
	Lift		Arm move up command	Arm displaces vertically	Pilot through PC OP's keys, commanding IHM, sends a wireless signal using Bluetooth modules to I'ROBOTs control board which activates arm driving motor.
	Drop		Arm move down command	Arm displaces vertically	
Detect	Path		IR sensor values (Line following sensor)	Motor commands	A line following algorithm inside I'ROBOTs control board reads sensor values and acts by commanding motors to change direction and stay in the line
Setup	Setup Mechanics		Mechanics inspection results	Fine tuning, change or repair of mechanical elements	Maintenance technician uses tools to diagnose, calibrate, change and/or repair mechanical and electronical parts of I'ROBOT
	Setup Electronics		Electronics tests results	Fine tuning, change or repair of electronics elements	
Charge	Battery		Battery charge measurement	Battery charging if necessary	Maintenance technician evaluates if I'ROBOT needs to be charged, if it does battery is replaced with the spare and charged

2.2.2. Functional and dynamic architecture

The design of the functional and dynamic architecture of the system was realized by considering the specifications which describe the route of PROTEC'SYS in several sequences. The architecture is based on each sequence, describing the main functions that are move (automatically and manually), carry (grasp, transport and unload the container) with their different input and output parameters and secondary functions (listen, maintain, setup, locate).

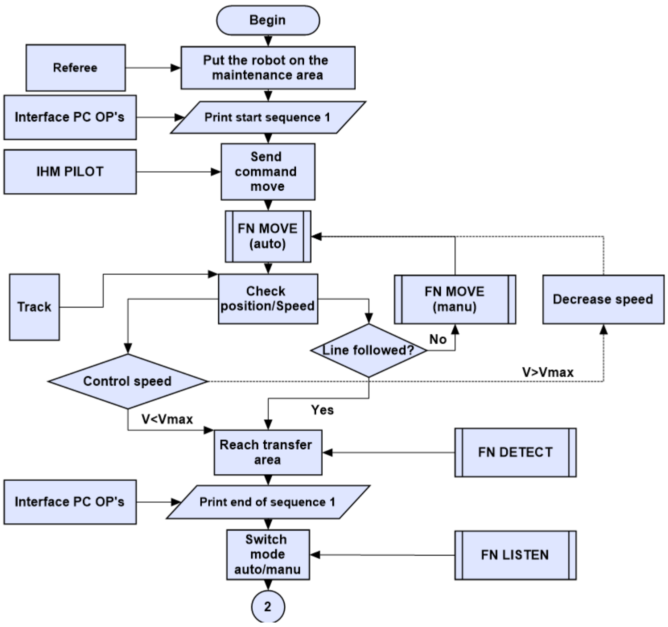

Figure 4: Flow diagram for process 1.

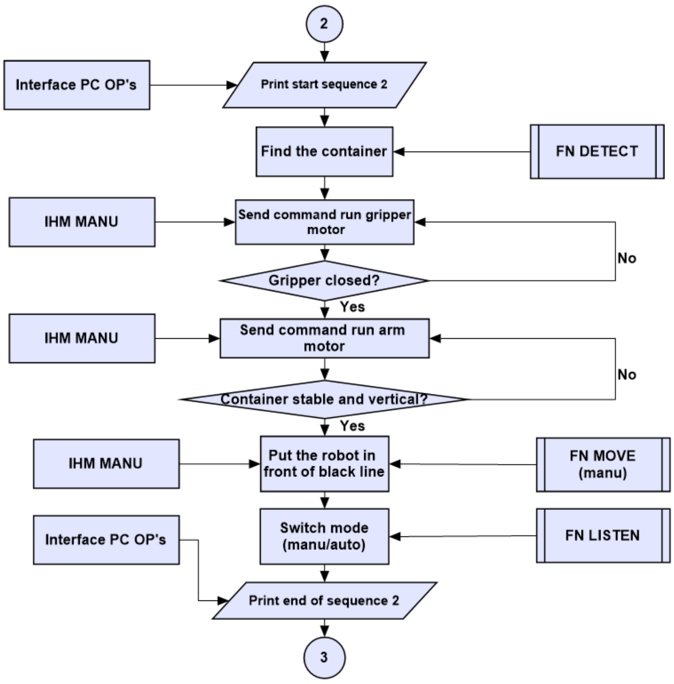

Figure 5: Flow diagram for process 2.

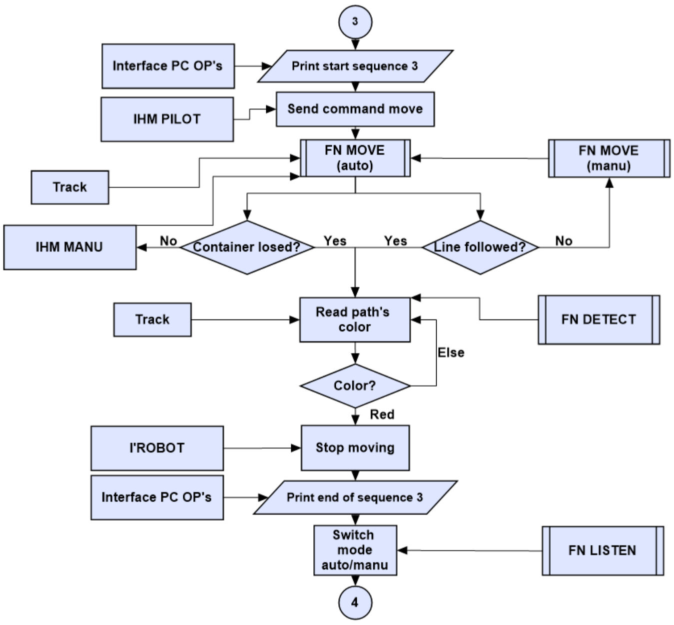

Figure 6: Flow diagram for process 3.

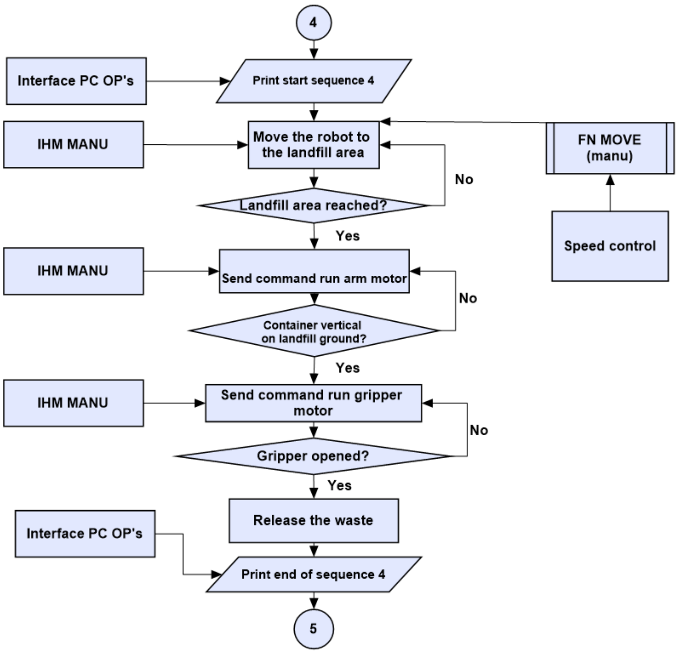

Figure 7: Flow diagram for process 4.

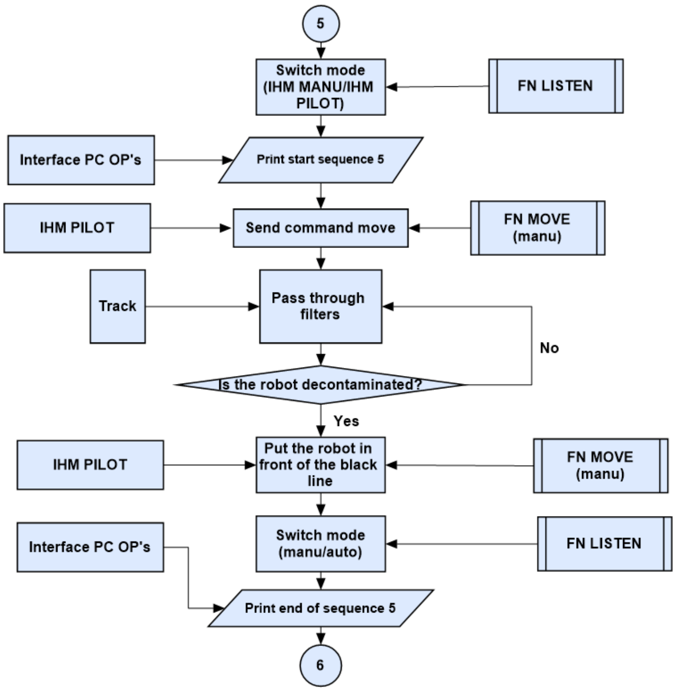

Figure 8: Flow diagram for process 5.

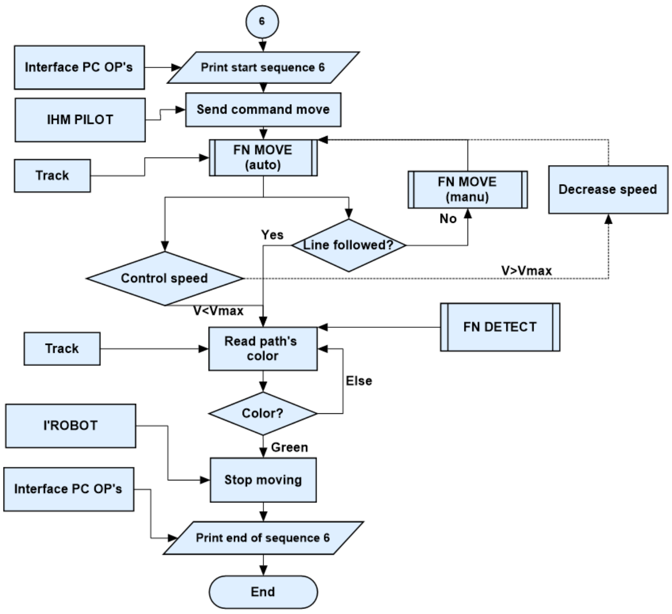

Figure 9: Flow diagram for process 6.

The main inputs are the instructions of the responsible of security (referee), the track and the speed limits. The robot is driven by the driving and handling operators (IHM MANU and IHM PILOT) via PC OP's. They use the function "listen" to follow instructions and synchronize their actions. The secondary function detect can be visual or executed using the sensors I'ROBOT is equipped with.

2.3. ORGANIC AND PHYSICAL ARCHITECTURE OF THE SYSTEM (LOT P23)

2.3.1. Organic / physical tree of each architectural solution

In this section the constitutive elements of PROTEC'SYS and its physical links are described.

Table 11: Organic / physical tree of each architectural solution.

Designation	Constitutive elements	Mission
I'ROBOT	Mechanical devices Electronic devices Microcontroller Battery	Move through the reprocessing center, carry the waste from transfer area to confinement zone
PC OP'S	IHM MANU IHM PILOT	Coordinate PROTEC'SYS missions, display each process of the mission
Driving operator	-	Control the displacement of I'ROBOT
Manutention operator	-	Deals with container which is carried and dropped
Maintenance operator	-	Check and repair failures, replace batteries and calibrate sensors eventually after each loop
Remote control	Joystick	Make easy manipulation of

	Touch screen	the robot
	Keyboard and mouse	
Command and communication device	Bluetooth module	Transfer data between PC OP's and I'ROBOT
Microcontroller	MegaPi board	Microprocessor of the robot. Read inputs and send output commands
Battery	-	Provide energy to the robot
Mechanical devices	Chassis, wheels, motors, picker	Ensure the locomotion of the robot and the manutention of the waste
Electronic devices	Sensors	Convert physical data into digital information

2.3.2. Organic / physical architecture of each architectural solution

The physical architecture of the whole system is described in order to show the interconnections between the system, subsystems and other components.

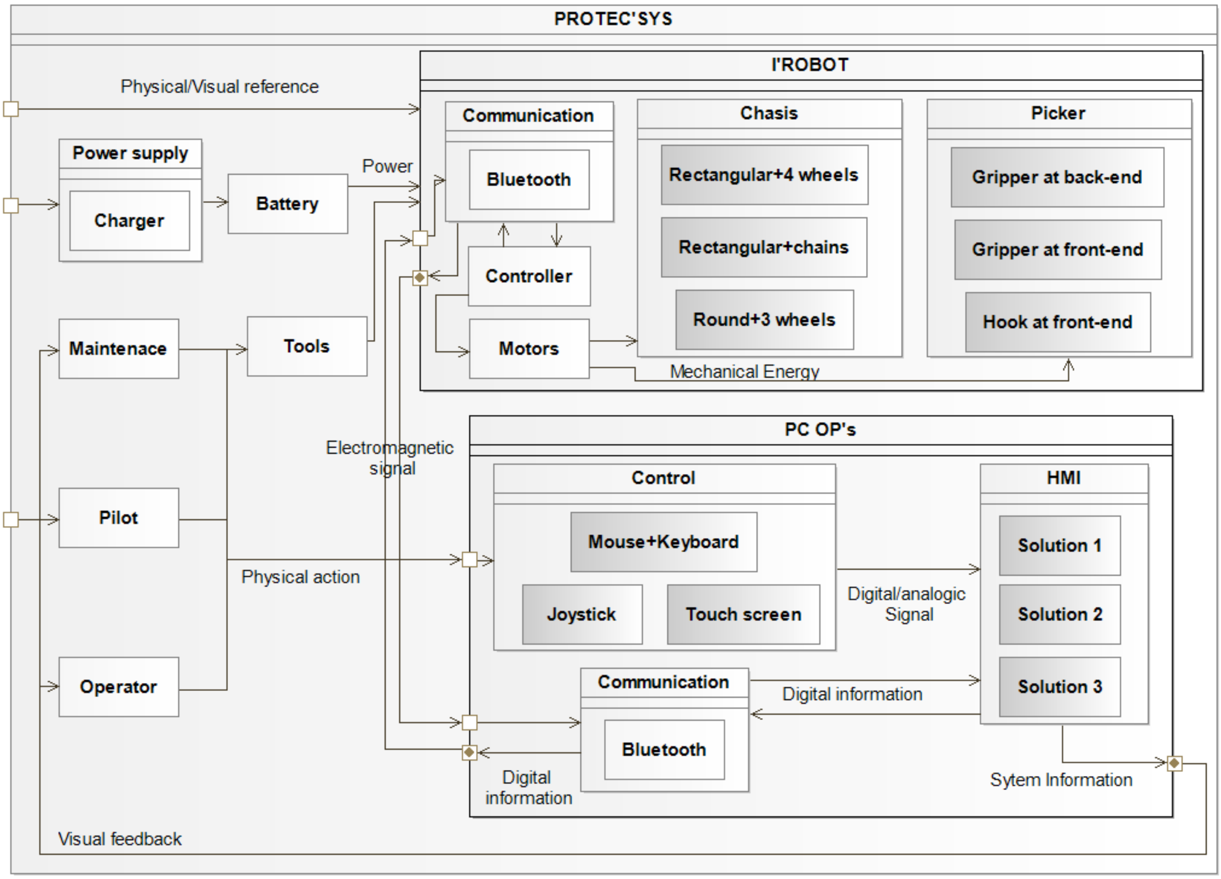

Figure 10: physical architecture of the system.

In the description of the physical architecture of the system all possible solutions for each subsystem is displayed, this to show that the physical organization of the system is the same but by considering the advantages and disadvantages of each of the studied solution we are able to change the performance and adjust it to the task and other requirements and constraints; each one of these solutions are shown using the dark grey shaded blocks.

2.3.2.1. I'ROBOT Architecture

I'ROBOT Architecture is divided in Chassis and Wheels and Picker where each solution studied is briefly described.

Chassis and wheels:

Solution 1: Round chassis with three wheels
Widely used for line following application, 3-wheeled robots may be of two types: differentially steered (2 powered wheels with an additional free rotating wheel to keep the body in balance) or 2 wheels powered by a single source and a powered steering for the third wheel. In the case of differentially steered wheels, the robot direction may be changed by varying the relative rate of rotation of the two separately driven wheels. If both the wheels are driven in the same direction and speed, the robot will go straight. Otherwise, depending on the speed of rotation and its direction, the center of rotation may fall anywhere in the line joining the two wheels.

Figure 11: Round chassis with three wheels.

Solution 2: Rectangular chassis with four wheels
Highly used in the robotic world; it provides high level of stability at high speeds (More stable than the three-wheel version since the center of gravity must remain inside the rectangle formed by the four wheels instead of a triangle). This leaves a larger useful space. Still it's advisable to keep the center of gravity to the middle of the rectangle as this is the most stable configuration, especially when taking sharp turns or moving over a non-level surface.

Figure 12: Rectangular chassis with four wheels.

Solution 3: Rectangular chassis tracked robot
Continuous tracks, also called tank treads or caterpillar tracks, are a system of vehicle propulsion in which a continuous band of treads is driven by two or more wheels.
This type of vehicles have contact with a larger surface area than all the above mentioned Types, and as a result exert a much lower force per unit area on the ground being traversed than a conventional wheeled vehicle of the same weight. This makes them suitable for use on soft, low friction and uneven ground.

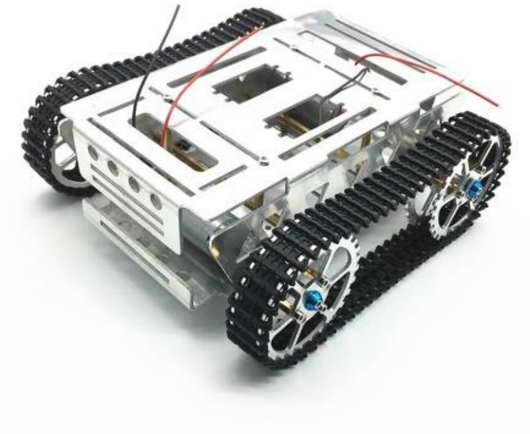

Figure 13: Rectangular chassis tracked robot.

Picker

The main role of the picker is to take the load vertically and to hold it in a stable position and then place it. In order to achieve that, a special architecture of the arm should be selected to keep the load in a vertical position. We will consider a single degree of freedom system able to move the load vertically using either the gripper offered in the Kit or a hook constructed using the mechanical parts.

Solution 1: Horizontal pick and place armed gripper placed on the back-end of the robot
Widely used for industrial application, the pick and place armed gripper was proposed.

Figure 14: Horizontal pick and place armed gripper placed on the back-end of the robot

Solution 2: Horizontal pick and place armed gripper placed on the front-end of the robot
Same as discussed in the previous solution, this solution will be again taken into consideration but now with the base attached to the front of the robot and les length when extended.

Solution 3: Horizontal pick and hold armed hook placed on the front-end of the robot
Like the architecture discussed in the previous part, the base attached to the front of the robot will be considered but the gripper will be replaced by a hook.

2.3.2.2. HMI Architecture

The PC OP's of PROTEC'SYS has two main roles: the first is to control the robot via the HMI operators and the second is to visualize the critical information related to the mission. We will therefore propose interface solutions for remote control and then those relating to the display of data.

Remote Control

The control or input parameters of the IROBOT necessary for its control are the position, the orientation (left, right, rotation), the speed (accelerate, decelerate), the change of mode (automatic, manual, running, stop) and phase or sequence. The three considered designs for the HMI inside PC OP's which will be controlling I'ROBOT system are described as follow. These include a joystick (solution 1), a touch screen (solution 2) and the keyboard + mouse device (solution 3).

Solution 1: Joystick
Control the robot using a joystick connected to the PC OP's by cable or Bluetooth. The control commands of the robot (moving, carrying and dropping the container) are executed with the buttons of the joystick.

Solution 2: Touch screen
Control the robot by a touch screen. This can be the PC OP's screen, or a tablet also connected and provided with a graphical interface with control buttons.

Solution 3: Keyboard and mouse
Send instructions to the I'ROBOT via the OP's PC keyboard and mouse. The movements of the robot and its lifting arm are obtained using the directional keys of the keyboard, the speed control by the numeric keypad and the choice of a mode or switching from one sequence to another are executed by using the mouse.

System information display

The system information output from PROTEC'SYS and observable on the PC OP's screen are the sequence, the state of the sensors, the speed, the operating mode, the time, the state of charge of the batteries, the stability.

Solution 1:
Information can be displayed by sequence or step. Each sequence with its information will correspond to a different window.

Solution 2:
Offer a graphical interface whose information will be grouped according to the operating mode of the robot (manual, automatic, on, off). When switching between modes (different windows) will be necessary a change of operator.

Solution 3:
Single graphical interface window with different colors and alerts, easy to understand gauges and control buttons with visual feedback offering operators the possibility to interact simultaneously with the system.

3. SELECTED ARCHITECTURE JUSTIFICATION (LOT P40)

3.1. I'ROBOT

3.1.1. Chassis and wheels

Table 12: Chassis and wheels selection.

Main benchmarks	Solution 1	Solution 2	Solution 3
Stability	30%	70%	90%
Surface Contact	30%	60%	80%
Maneuverability	70%	50%	55%
Ease of Use	80%	70%	60%
Power Distribution	40%	60%	80%
Total	50%	62%	73%

Solution 1: Round Chassis with three wheels
The main advantage of this type of robot is that it affords a high level of maneuverability but lacks control and often loose stability on rough terrains/surface. Since we have rough surfaces to handle on the track, this type of model won't be a good solution. Solution not selected

Solution 2: Rectangular Chassis with four wheels
This type of architecture needs a lot of tuning and a very advanced steering control to achieve stable and controllable motion on curved path, Moreover, this type of application is not enough stable on rough terrains. Solution not selected.

Solution 3: Rectangular Chassis tracked Robot
Ideal for rough terrains, this type of design affords high level of controllability and maneuverability at low to medium speeds, provides as much traction as possible and most importantly distributing the weight of the robot evenly. For our application, this robot will afford high maneuverability on the line following and high stability on the rough terrains. Solution selected

3.1.2. Picker

Table 13: Picker selection.

Main benchmarks	Solution 1	Solution 2	Solution 3
Robot Center of Gravity	20%	80%	80%
Compact Architecture	30%	60%	90%
Weight	40%	40%	80%
Arm-Object adhesion	80%	80%	50%
Arm Maneuverability	90%	60%	60%
Total	55%	64%	72%

Solution 1: Horizontal pick and place armed gripper placed on the back-end of the robot
This type of mechanism affords multi degree of freedom motion and allows moving objects with high precision within the working platform. But with the height limitation of the robot we have and the high center of gravity it will creates this solution won't be a good fit. Solution not selected

Solution 2: Horizontal pick and place armed gripper placed on the front-end of the robot
To be able to overcome the instability created by the hand placed in the back; it was placed in the front-end of the robot. This will create a lower center of gravity of the whole system and will allow the whole robot to have more compact volume. Solution not selected

Solution 3: Horizontal pick and hold armed hook placed on the front-end of the robot
The center of gravity will also be low and the final architecture will be more compact, also the weight of the overall structure will be reduced Solution selected

3.2. HMI

3.2.1. Remote control

The following table summarizes the performance of each proposed control interface solution.

Table 14: Remote control selection criteria

Main benchmarks	Solution 1	Solution 2	Solution 3
Ergonomics	90%	80%	80%
Precision	90%	80%	90%
Time response	50%	80%	80%
Device programming	30%	50%	50%
Display of information	10%	90%	90%
Total	54%	76%	78%

Solution 3: Keyboard and mouse
It is accurate, easy for programming and quite ergonomic. Each command can be associated with a key of the keyboard with the possibility to change their intensity and to choose the operating modes. The display of PROTEC'SYS information is directly accessible on the computer screen. Solution selected

3.2.2. System information display

Chosen architecture for the HMI was solution 3 it offers more advantages that the other two, it encapsulates functions reducing possibilities of human error, mode selection buttons make it more intuitive to use; each one of the indicators let the user see in which state is the mission, those can be organized such that the operator don't lose any important information. Java programming language was selected to build the HMI, it was chosen considering the skills and experience of each one of the team members.